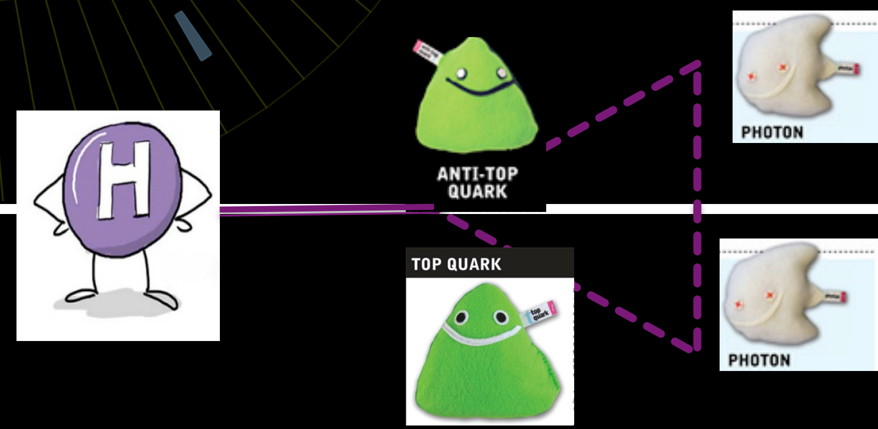
Higgs Decaying into Two Photons

Rishi Patel



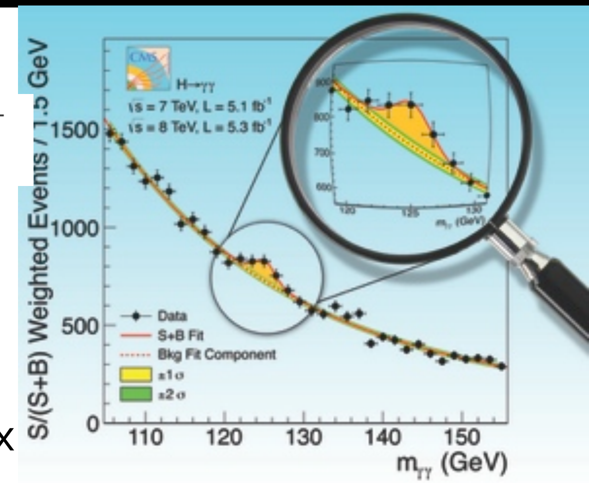
International Conference on New Frontiers in Physics

An Important *Signature*: H→γγ

- Branching ratio of less than 0.3%, but the CMS detector gives a well measured di-photon 4-momentum

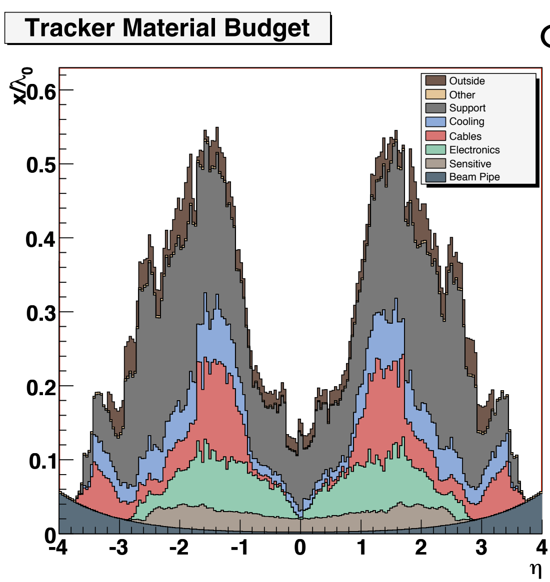
Picture for Discovery:

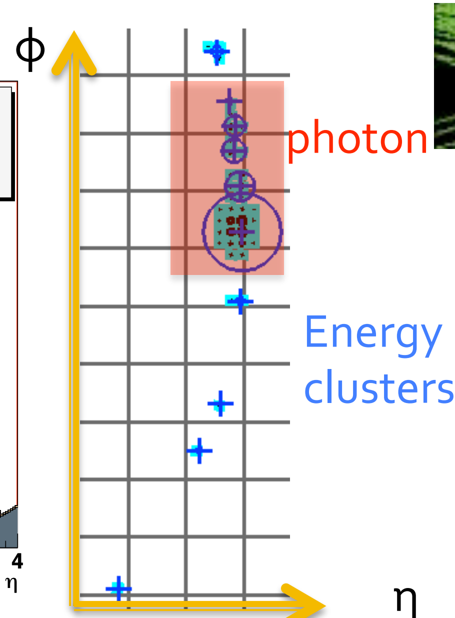
$$m_{\gamma\gamma} = \sqrt{E_{\gamma 1} E_{\gamma 2} \left(1 - \cos(\theta_{\gamma\gamma})\right)}$$

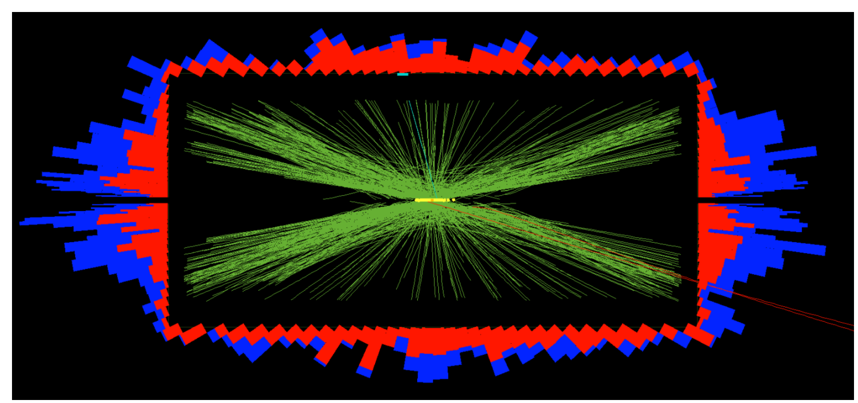


Need to Sharpen the Picture:

- Photons fragment before they reach the calorimeter and e+/e- pair spread out in the magnetic field
- Additional interactions muddy the energy and the signal vertex is crowded by other vertices







Analysis Chain

CMS Reconstructed Photons

Vertex Finding

Energy Corrections

Energy Smearing

Photon ID and Event Classification

Selected Higgs Events

Selected Higgs Events

Vector Boson Fusion

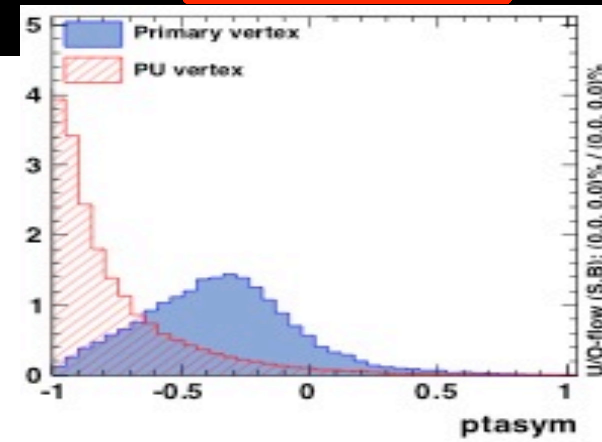
Higgs+V Production

Higgs+$t\bar{t}$ Production

Gluon Fusion Production

Vertex Finding

$$m_{\gamma\gamma} = \sqrt{E_{\gamma 1} E_{\gamma 2} (1 - \cos(\theta_{\gamma\gamma}))}$$



UNCONVERTED PHOTONS

- Combine di-photon pT with sum Track pT of vertices to use as discriminator

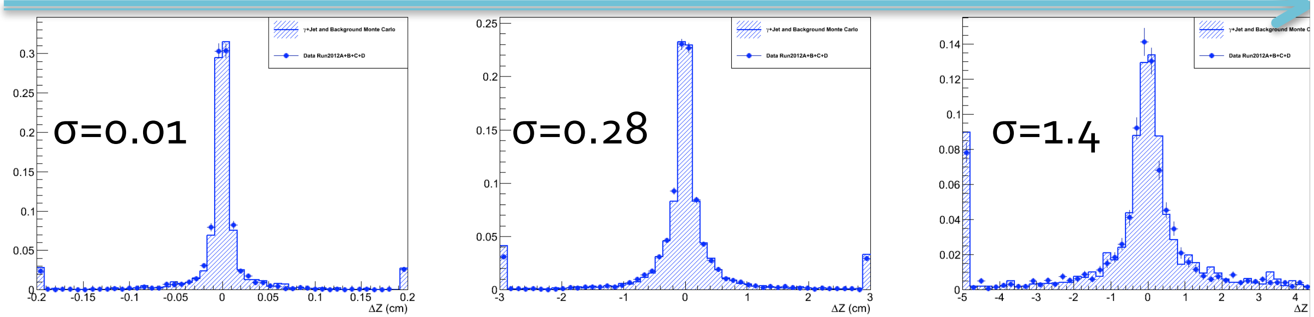
CONVERTED PHOTONS

- 2 complementary methods to give a combined measure:
  - Use momentum of e+/e- pair only (project it onto the beam-line)
  - Use impact point on the ECAL+conversion vertex (line)

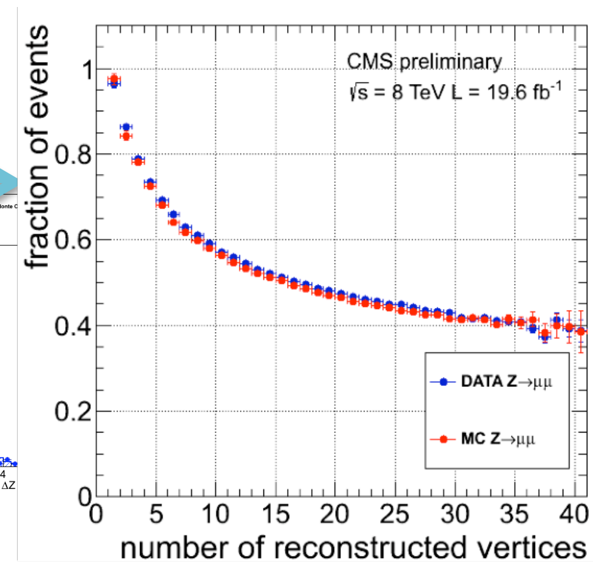
Conversion information and kinematic variables combined in an MVA classifier. MVA is validated with Z to μμ

Conv. Track info only

Larger Conv. Radius



Pixel TIB TOB



Energy Corrections

$$m_{\gamma\gamma} = \sqrt{E_{\gamma 1} E_{\gamma 2} (1 - \cos(\theta_{\gamma\gamma}))}$$

SQUEEZE the ECAL energy resolution

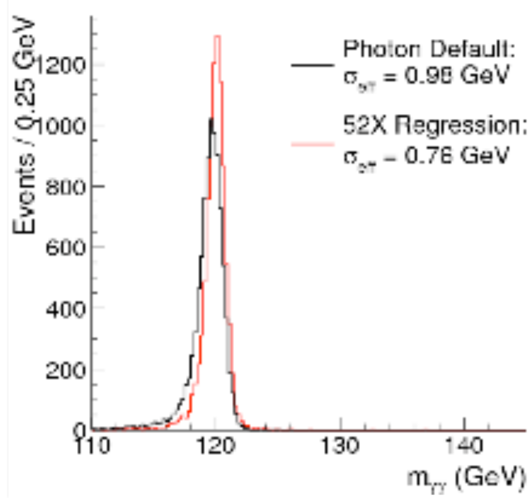
MVA Regression trained on Simulation:

- Dominantly improve the large number of fragmented photons
- Well measured energies can be further improved: EM Shower leakage

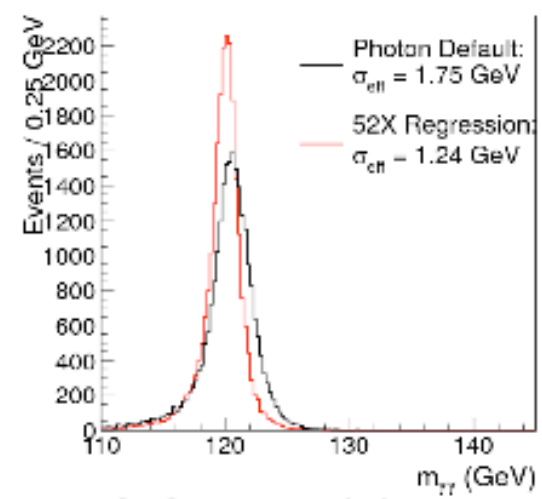
FROM SIMULATION TO DATA:

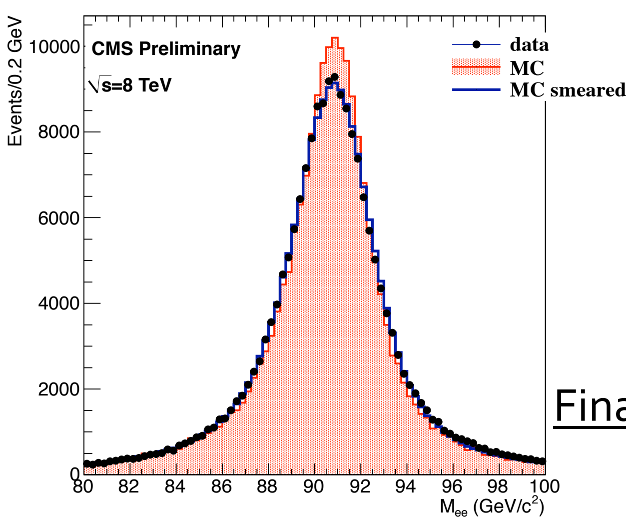
- Use the Z to ee simulation and data to derive the smearing
- $E_{MCSmear} = E_{MC} * Gaus(\sigma)$ where σ is determined to give the closest match to the data

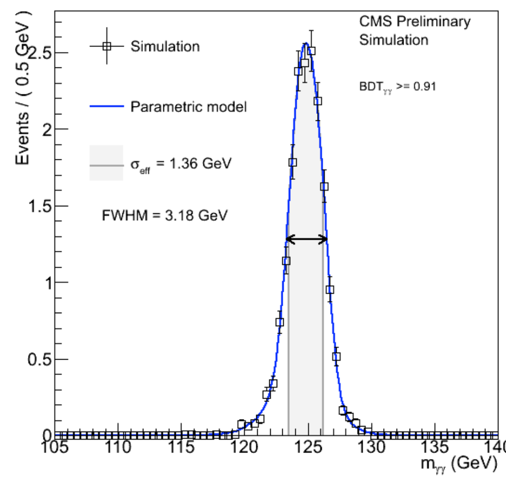
UNCONVERTED

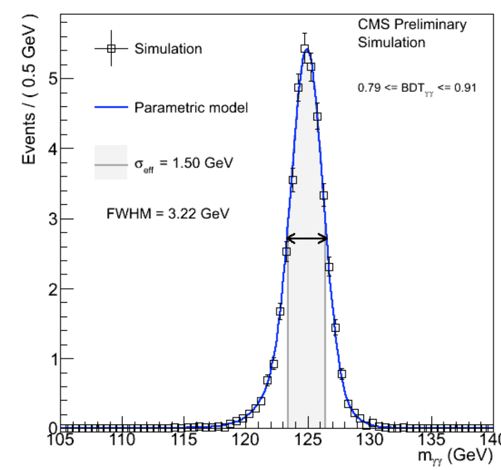


CONVERTED









Final Signal Resolution in ECAL Barrel: 1.4 to 1.50 GeV

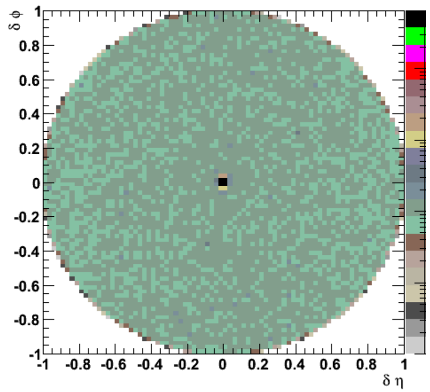
Tackling the Reducible Background

- **Advantages of a granular detector for photon identification**

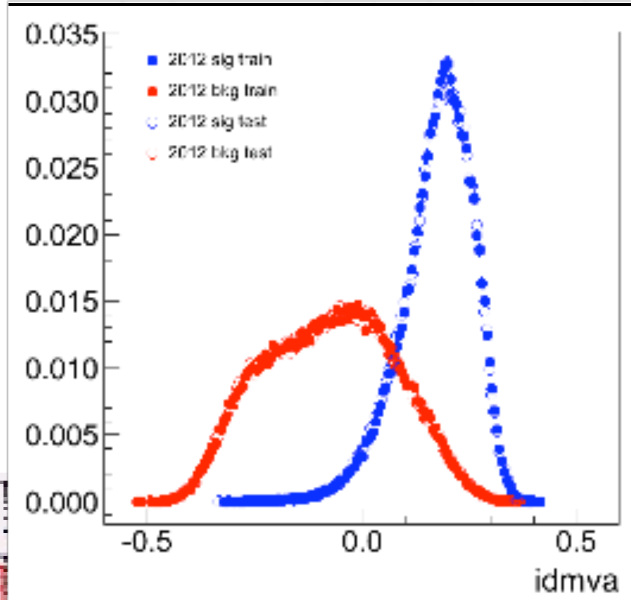
Energy Profile from Reconstructed particles

Energy profile for charged particles around the signal photons (from PU).

A blip in the map would indicate some hadronic activity (indicating a fake photon)

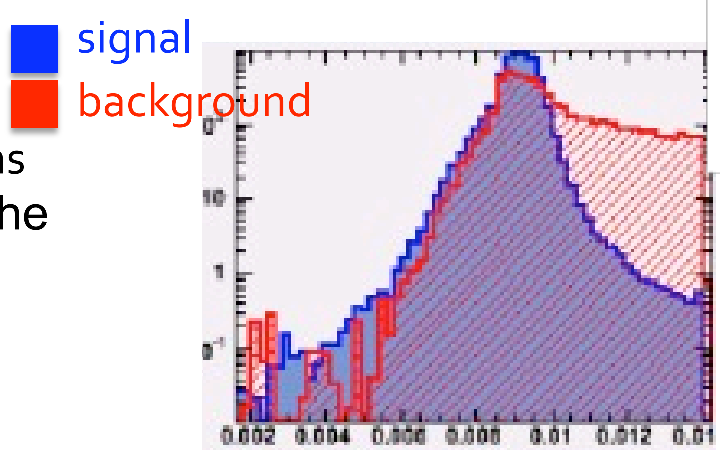


Most discriminating variables combined into an MVA classifier



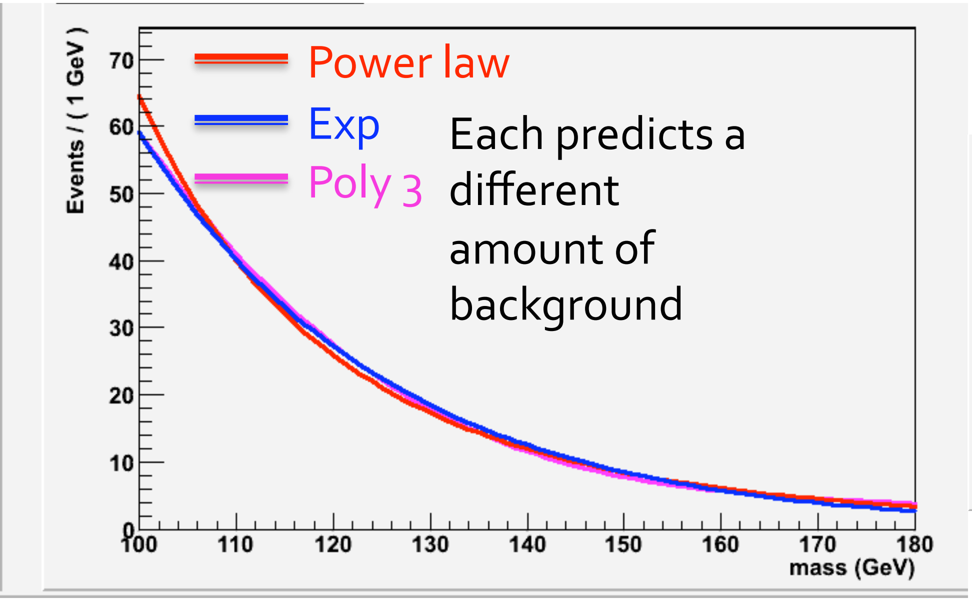
EM Shower Shape for discrimination

Particular shower shape variable that discriminates photons from pi0 based on the crystal spacing in η

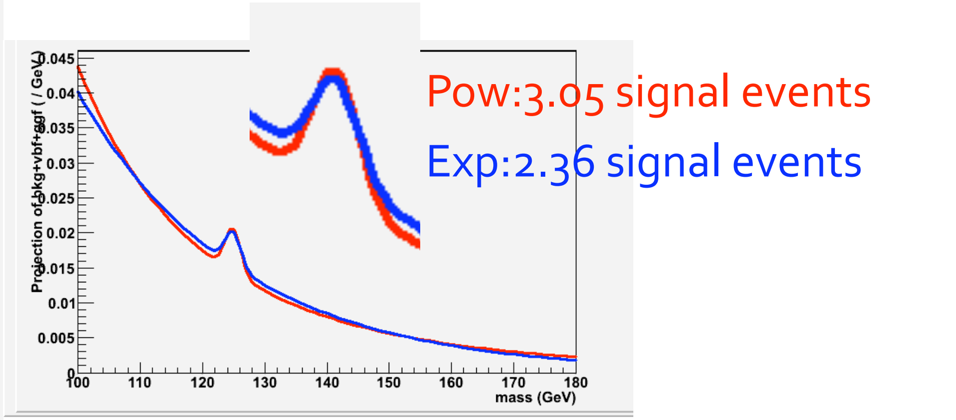


Modeling the Background

Background model fit to data (don't know what the "true" function should be)



Resultant Signal Bias:



STRATEGY: Test a families of functions. Measure the pull of the signal in pseudo-data generating from one background function and fit to another function

SOLUTION: A polynomial of large enough order gives very small signal bias when fit to different pseudo-data from various functions

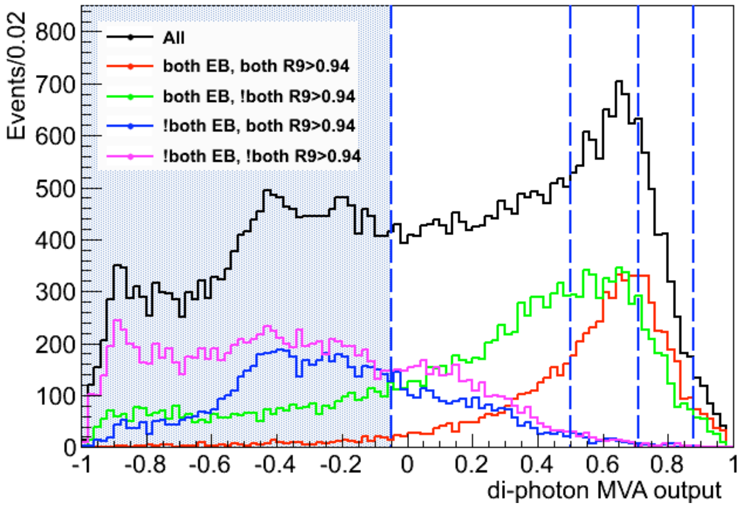
Event Classification

$$m_{\gamma\gamma} = \sqrt{E_{\gamma 1}E_{\gamma 2}\left(1 - \cos(\theta_{\gamma\gamma})\right)}$$

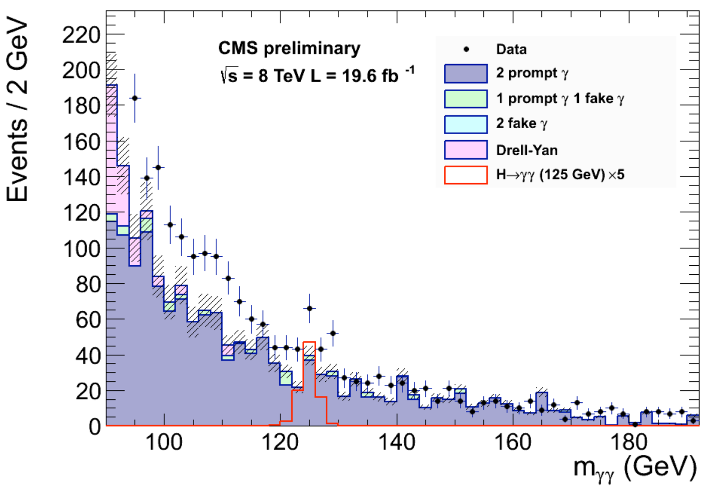
Increase sensitivity by dividing the data according to the signal-to-background ratio:

- Factors that affect sensitivity: **detector resolution, kinematics of di-photons**, how well chosen the vertex is and how well the photons are identified
- MVA discriminator defines 4 categories with different S/B

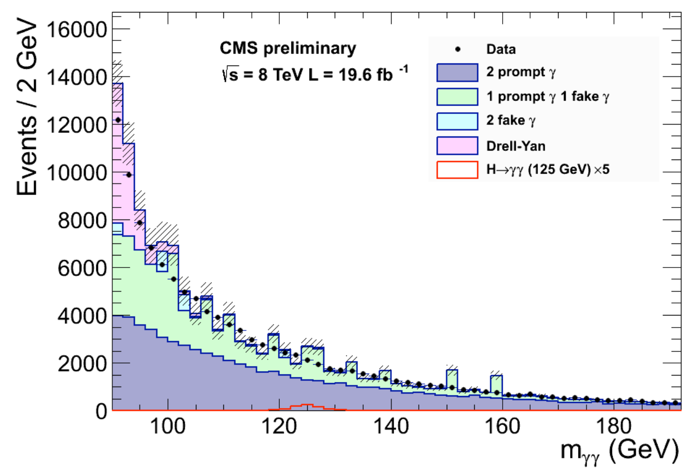
Combine into an MVA



Highest S/B category

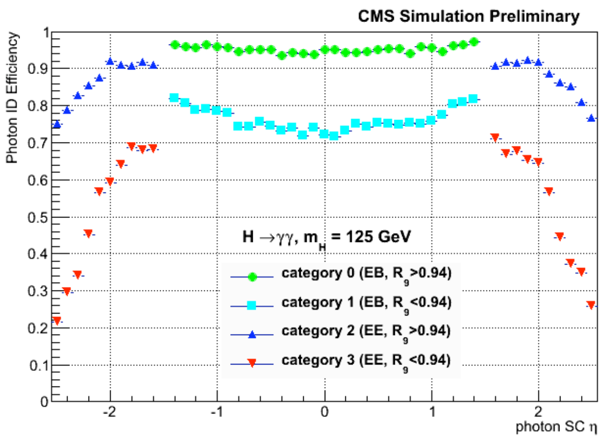


Lowest S/B category

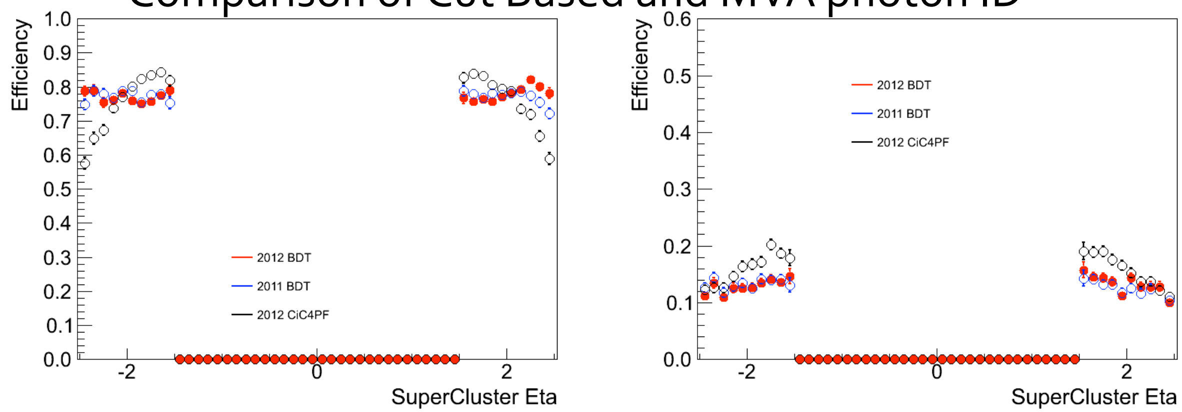


CUT-BASED Analysis

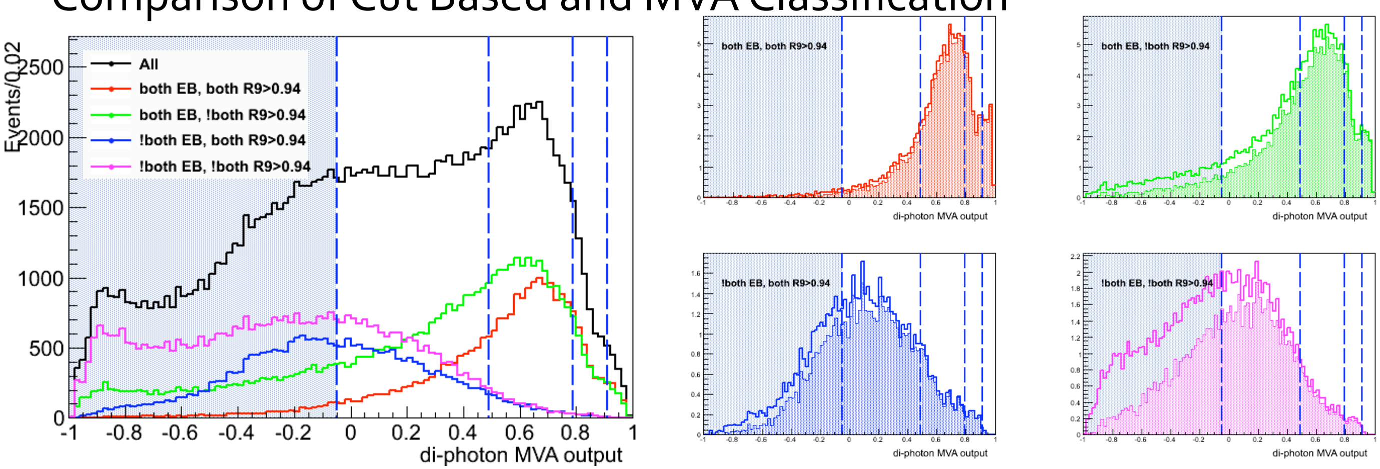
- As a parallel analysis, there is a more traditional cut-based analysis: applying ID cuts in four categories of detector resolution



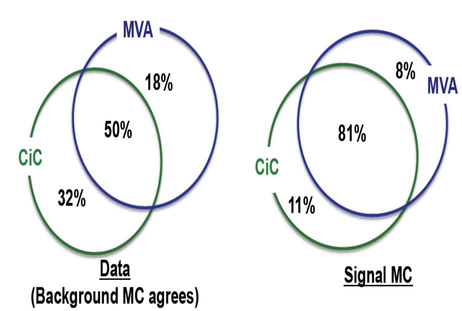
Comparison of Cut Based and MVA photon ID



Comparison of Cut Based and MVA Classification



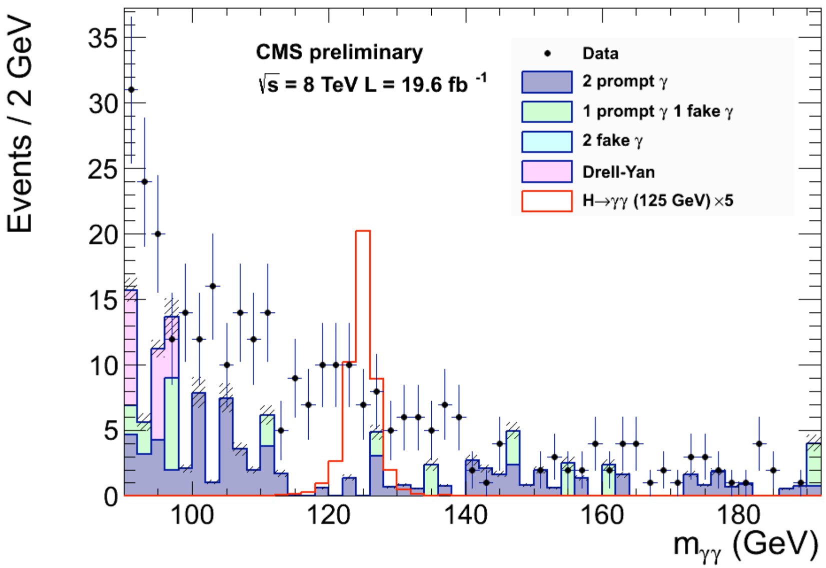
Overlap



Exclusive Tags

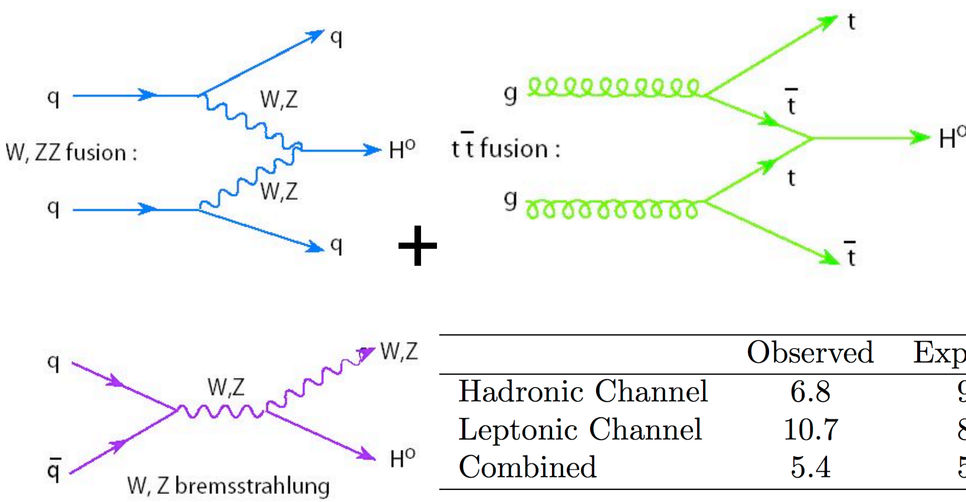
- Further classifying by production mode boosts the sensitivity: additional objects in the final state

DIJET TAG for large M_{JJ}



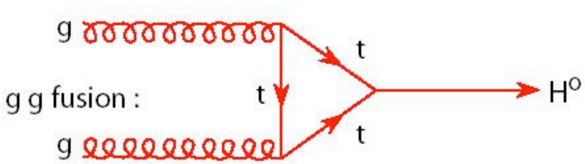
NOW

NEW

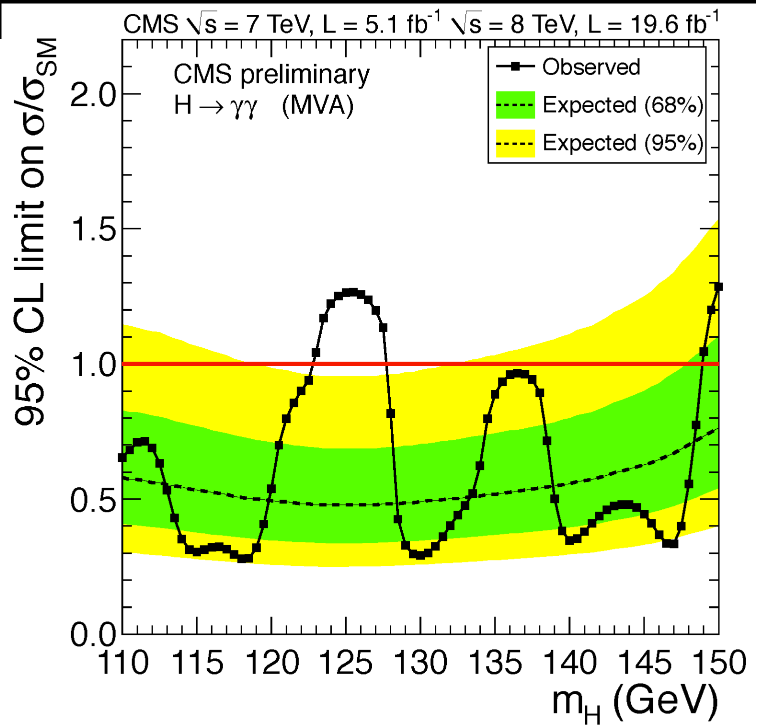


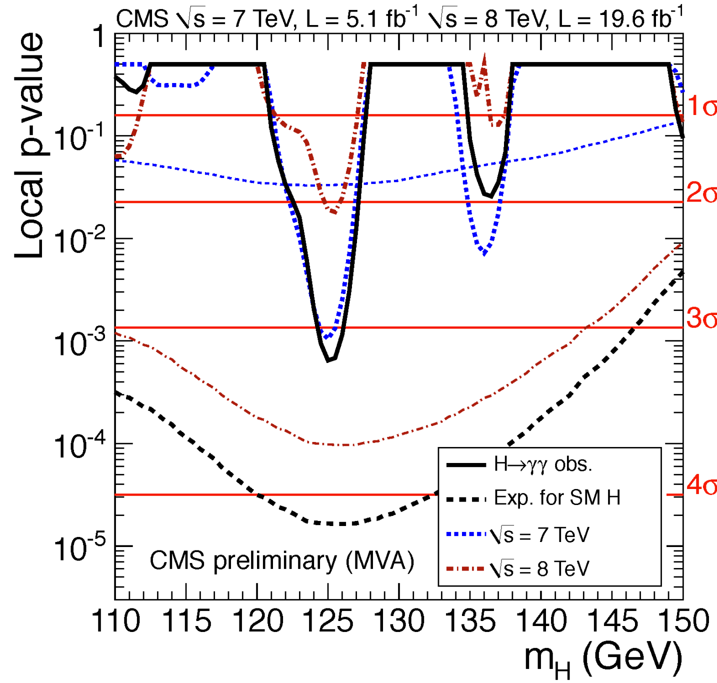
	Observed	Expected
Hadronic Channel	6.8	9.2
Leptonic Channel	10.7	8.0
Combined	5.4	5.3

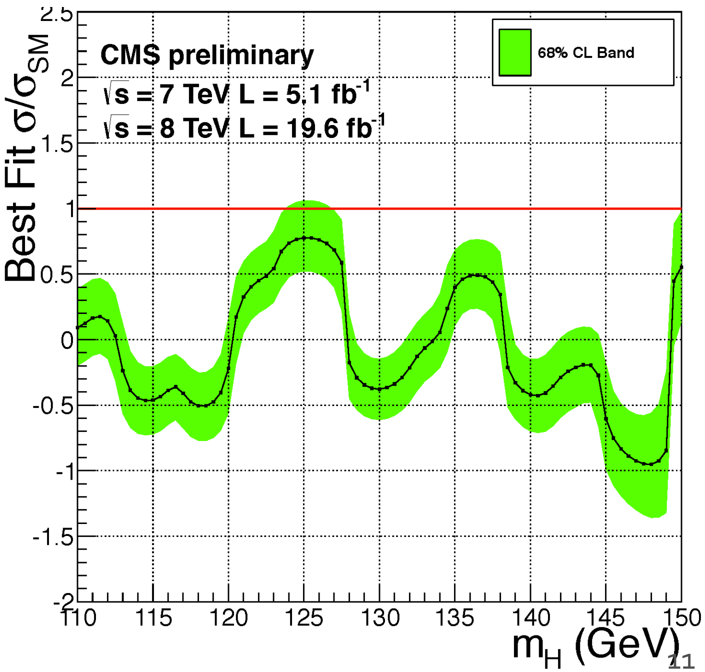
- Important for comparing Higgs coupling to fermions (untagged) and vector bosons (tagged)



RESULTS



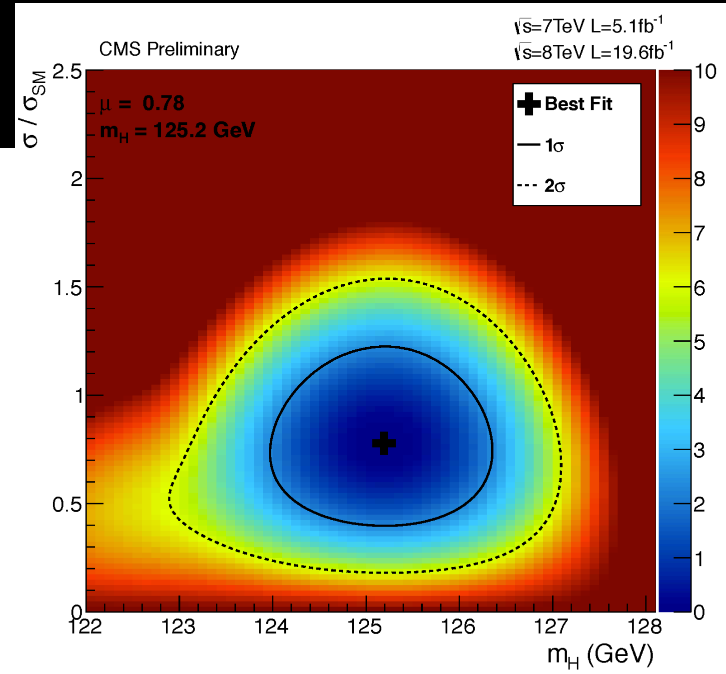




- Exclude Higgs mass outside [123.5,128] at 95% CL and the significance of the excess at 125 GeV is 3.2σ
- Best fit signal strength at mass 125 is 0.78_{-26}^{+28} times the SM cross-section

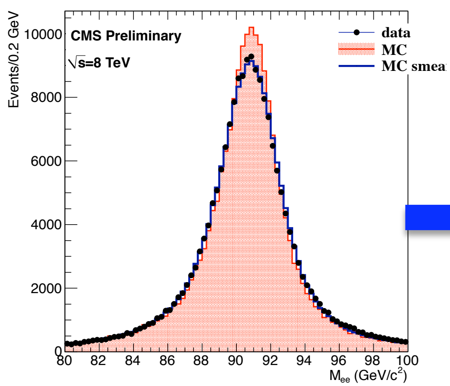
Mass Measurement

- Fitting for the signal strength and the mass gives the best fit mass at 125.2±0.5±0.8

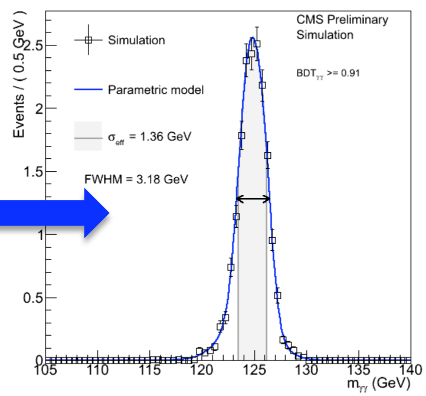


Reminder about the photon energy scale:

Z→ee



H→γγ

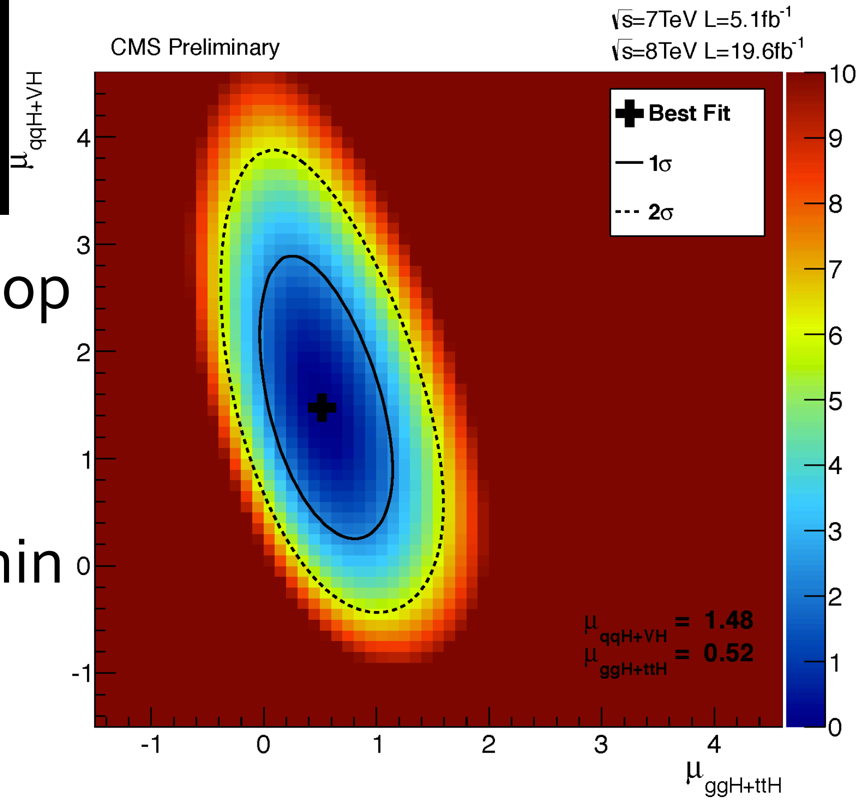


Systematic uncertainty :

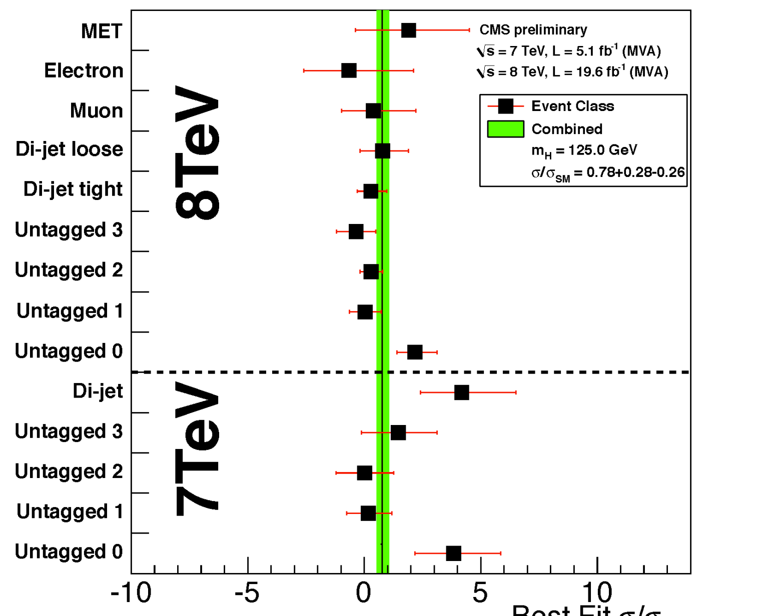
- Electrons/photon difference not simulated perfectly in the MC
- Need to extrapolate the energy scale for the Z mass to the higher mass of the Higgs boson

SM Compatibility

- Compare μ_F for Higgs coupling to top to μ_V coupling to Vector bosons
- Best fit : $\mu_F = 0.52$ $\mu_V = 1.48$ the SM production cross section is within the 68% CL contour



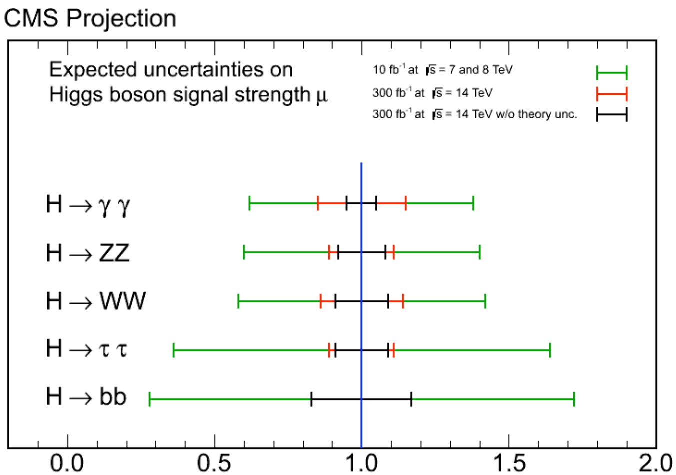
- The signal strength in individual event classes also shows strong compatibility with the SM Higgs production

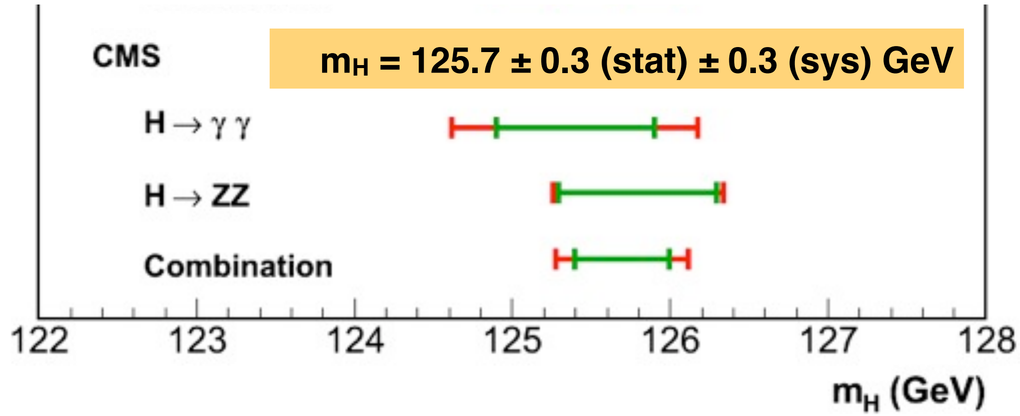


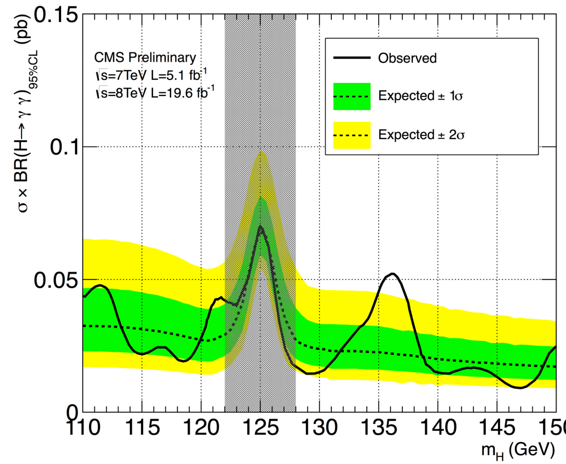
Conclusion

Analysis uses MVA techniques to chisel the picture of H→γγ

- Future projections show much smaller uncertainties on the signal strength and also increased precision on the mass measurement







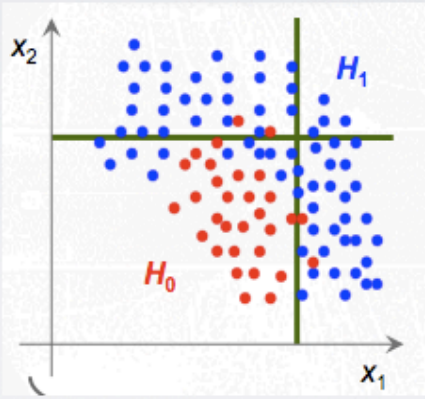
- NOTE: The analysis is general enough to look for additional Higgs-like states.
- Most significant excess at M_H=135 GeV with a significance of 2.97σ

ADDITIONAL MATERIAL

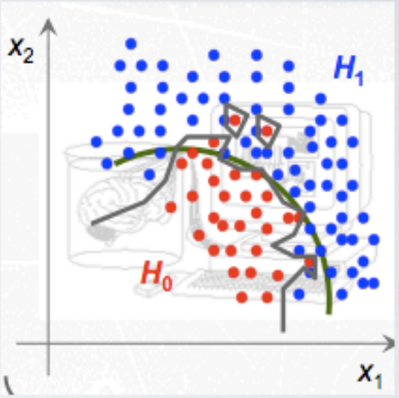
MVA TECHNIQUES

- Higgs Analysis requires a finely tuned discrimination between signal and background
- **Classification:**
  - Can categorize by choosing cuts on a few discriminating variables to sketch the signal-to-background ratio (assumes variables are independent)
  - More optimally can use many discriminating variables input to a learning algorithm that maps them to the signal-to-background ratio (models the correlation between two variables)

Choosing cuts by hand

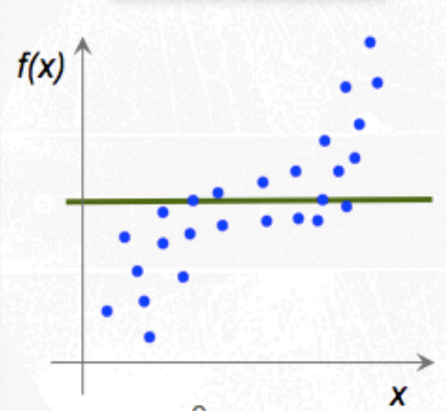


MVA to optimize the boundary

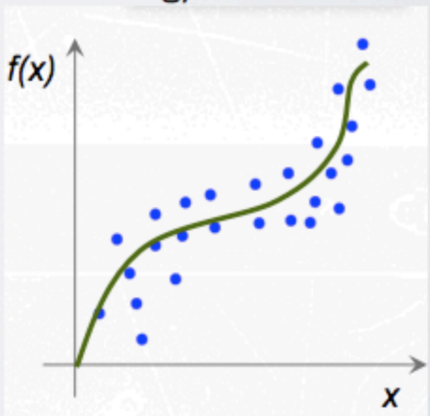


- Also to find a mass peak the analysis needs the best energy resolution
- **Regression:**
  - Can model the energy correction as a function of one variable e.g. estimate energy correction in eta bins
  - More optimally can model the energy correction as a function of many variables. Use a learning algorithm to map the input variables to an energy correction

Estimate the Energy Correction in bins of a variable



MVA to model a function of the Energy Correction



MVA REGRESSION TECHNIQUE FOR CALIBRATION: BOOSTED DECISION TREES

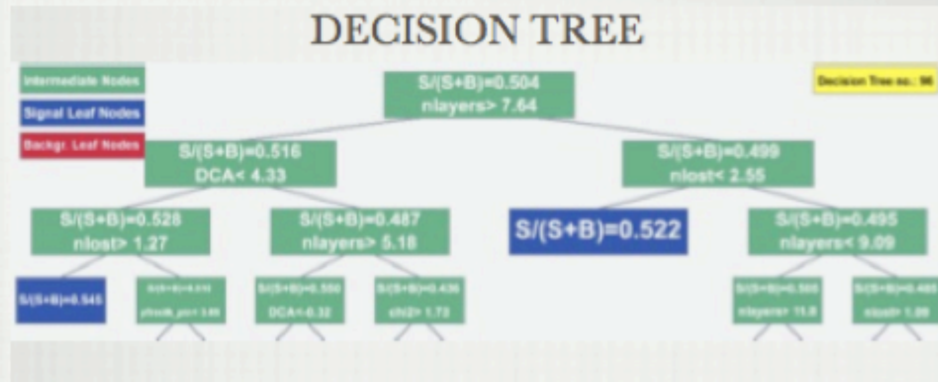
- ☐ Factorized Corrections: One can imagine using a set of variables that are dependent on the energy scale to define a set of categories and then estimate the scale in each category (e.g. bin in eta/r9)

- ☐ ONE STEP FURTHER MVA: The energy scale is really a continuous variable of several inputs.

  - ☐ Use logic tree which tries to group together photons with similar energy scale by applying a series of cuts on the input variables in a training sample (Photons from simulation)–finds local extrema in the parameter space of inputs.

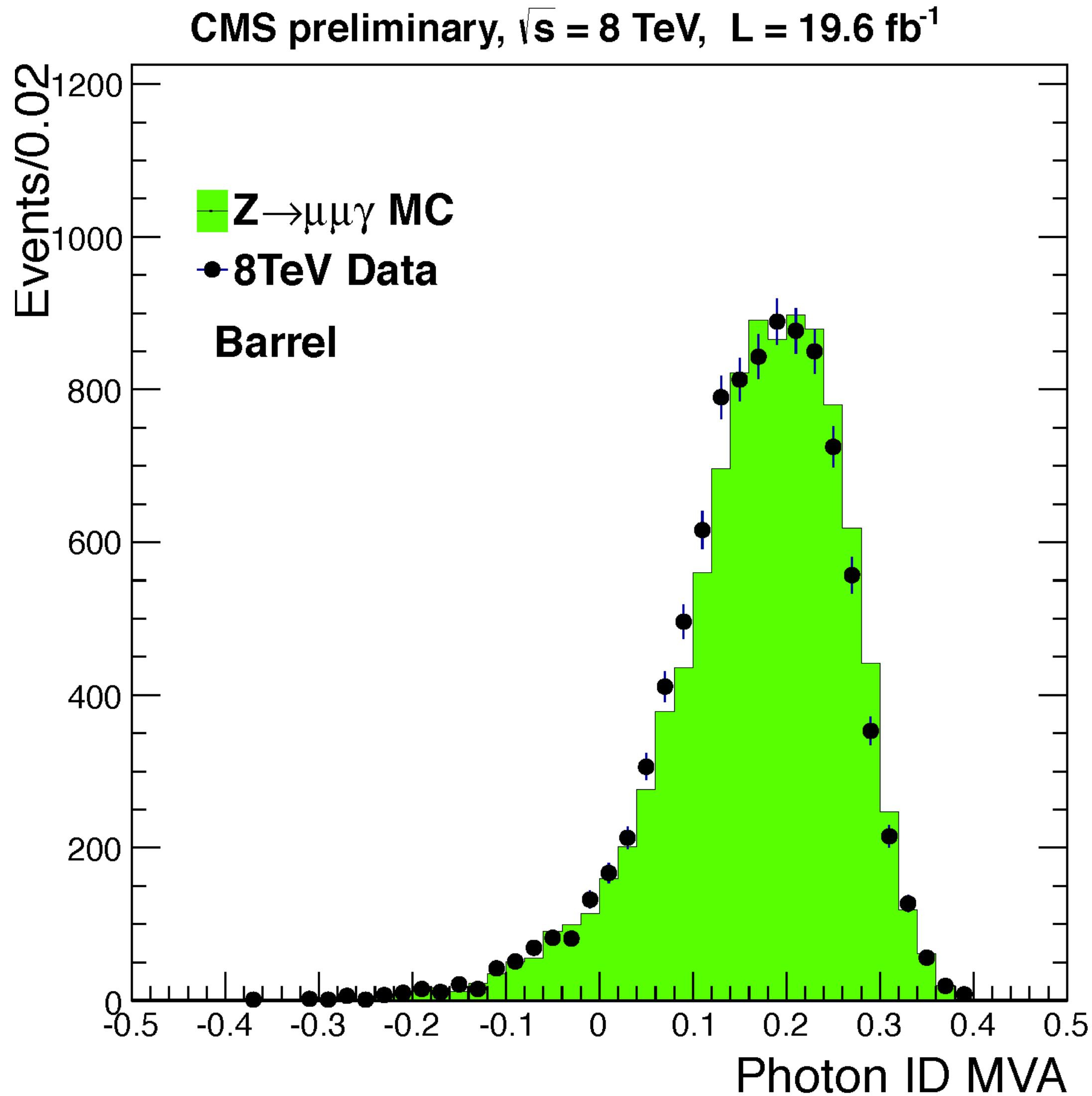
  - ☐ Create many such trees (boost) to smooth out noise from outlying events

  - ☐ Photon interaction with material is well modeled in simulation

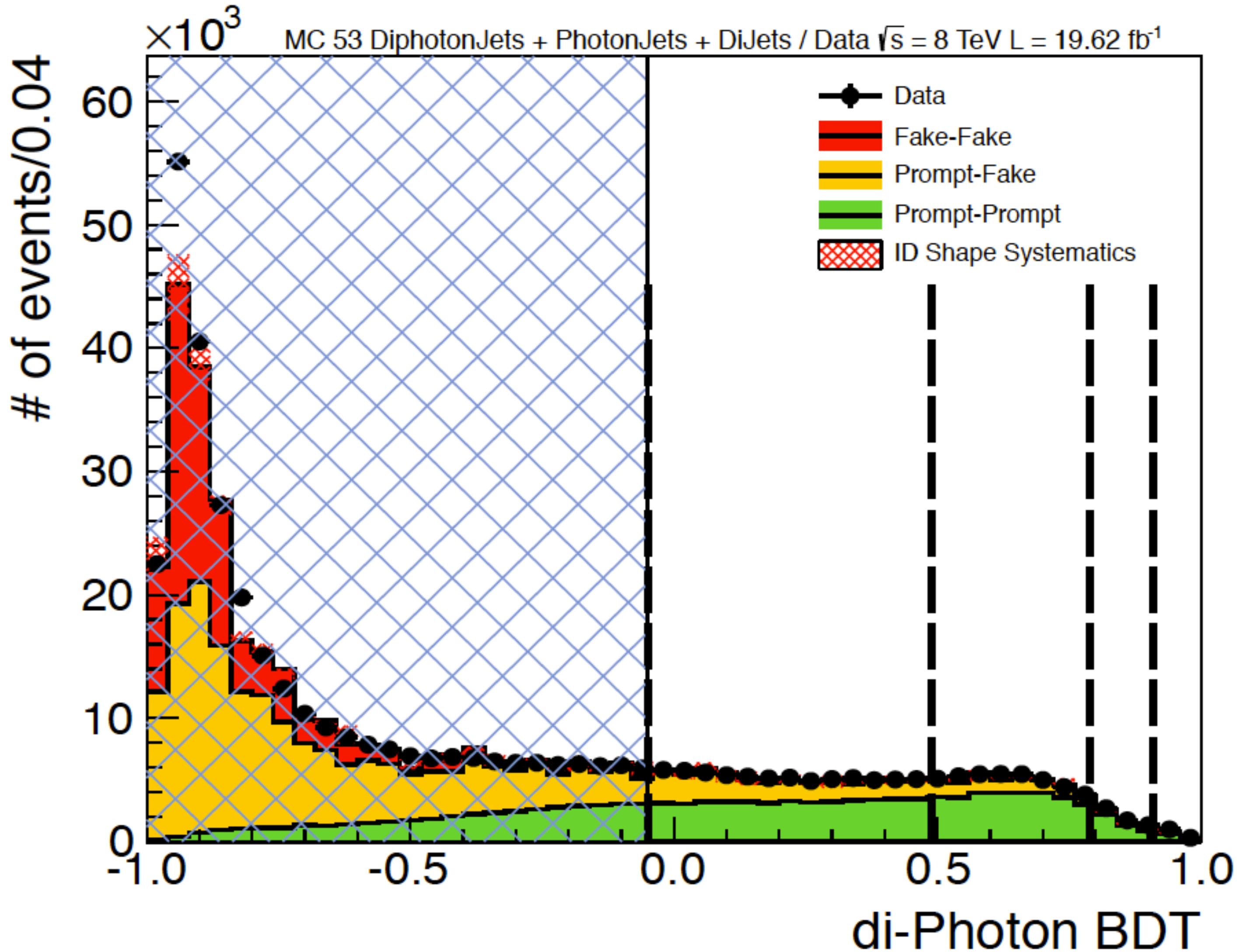


EXAMPLE: Here a decision tree is used to identify a track from a converted photon (signal) from tracks from charged pions (background) based on input variables (number of track layers, DCA to primary vertex etc). Blue boxes are where S/S+B is determined, in green the tree deepens to further split the parameter space

Photon Control Sample



MVA Categories



MVA -Cutbased Comparison

Low signal to background ratio a fundamental feature of the H→γγ channel.

- Uncertainty on the signal strength driven by statistical fluctuations of the background, and analysis changes can lead to statistical changes due to fluctuations of which events are selected, and their fluctuations of their mass (recalibration etc.).
- The correlation coefficient between the MVA and cut-based signal strength measurements is found to be r=0.76 (estimated using jackknife techniques).

	MVA analysis (at m_{H}=125 GeV)	cut-based analysis (at m_{H}=124.5 GeV)
7 TeV	$1.69^{+0.65}_{-0.59}$	$2.27^{+0.80}_{-0.74}$
8 TeV	$0.55^{+0.29}_{-0.27}$	$0.93^{+0.34}_{-0.32}$
7 + 8 TeV	$0.78^{+0.28}_{-0.26}$	$1.11^{+0.32}_{-0.30}$

Taking account of the correlation, the compatibility between the MVA and cut-based analysis measurements of the signal strength is found to be within 1.5σ for the combined 7 and 8 TeV measurement, and within 1.8σ for the 8 TeV measurement alone.